**Grassroots Journal of Natural Resources**, Vol.7 No.2 (August 2024)
ISSN: 2581-6853 | CODEN: GJNRA9 | Published by The Grassroots Institute
Website: https://grassrootsjournals.org/gjnr | Main Indexing: Scopus and WoS

**ISSN 2581-6853 | 7(2) Aug 2024**

**M – 00409 | Analytical Article**

# Is the Movement of Fertilizer and Food Commodity Prices Unidirectional? A Frequency Domain Causality Approach

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**How to cite this paper:** Nuno, D.B. (2024). Is the Movement of Fertilizer and Food Commodity Prices Unidirectional? A Frequency Domain Causality Approach. *Grassroots Journal of Natural Resources*, 7(2): 274-287. Doi: https://doi.org/10.33002/nr2581.6853.070214

**Received**: 12 August 2023
**Reviewed**: 30 May 2024
**Provisionally Accepted:** 01 June 2024
**Revised**: 23 June 2024
**Finally Accepted:** 25 June 2024
**Published:** 10 August 2024
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## Abstract

The 2008 economic crisis made food price to be doubled and currently the Ukraine-Russia war has resulted to higher food prices and costs of agricultural inputs like fertilizers are, thereby, drawing significant attention from scholars. This study was aimed at investigating the linkages between fertilizer prices and categorized food commodity prices using monthly data from January 1980 to May 2023. Relevant data was collected from primary and secondary sources. The Zivot–Andrew's unit root test, the Toda-Yamamoto time-domain causality test, and the frequency domain causality test were conducted for data analysis. Findings show that, at 5% significance level, grain prices induce the fertilizer price for all frequencies in the intervals of 0 to 3.14. This result suggests that there is both long-term and short-term causality from grains price index to fertilizer price index. In addition to this, fertilizer price causes the grains price for frequencies in the intervals of 1.08–1.64 and 2.71–3.14. These results indicate that fertilizer prices play a great role in predicting grain prices and have bidirectional causality with grain price. Furthermore, the empirical result from this study also reveals that fertilizer price index does not granger-cause the oil prices and other food prices for all frequencies in the intervals of 0-3.14, at 5% significance level. These results imply that fertilizer prices have no short-run and long-run causal relationship with oil prices and other food prices.

## Keywords

Bidirectional causality; Frequency domain; Time-domain; Toda–Yamamoto

## Introduction

Higher food prices bring crisis, food insecurity and poverty in the world. Hunger and diet quality are more affected by higher food prices (Bodirsky *et al*., 2015). Understanding the interdependency between food markets and fertilizer is vital for commodity price developments in general and food price developments in particular. The demand for fertilizers depends directly on the situation of the commodity market; so, fertilizer and food commodity prices follow the same pattern and the two markets are interrelated (Ott, 2012).

Rising fertilizer price brings higher food price, which is the main concern worldwide, particularly in developing countries (Bentley *et al*., 2022). Lower agricultural production and higher food costs result from producers using less fertilizers as a result of rising fertilizer prices (Brunelle *et al*., 2015; Yang *et al*., 2022). High fertilizer costs will result in fertilizer credits, which will increase the amount of inputs used to produce crops. Owing to the low profitability caused by high expenditures on inputs and low output prices, food prices and costs are high and significantly affecting crop yield (Arndt *et al*., 2023; Cedrez, Chamberlin and Hijmans, 2021).

Fertilizer and food commodities are currently receiving more attention following the conflict between Ukraine and Russia. Global market disruptions are caused by the sanctions placed on Russia, as well as other issues such as export restrictions on fertilizer (Arndt *et al*., 2023). Even food exports have an impact on food prices; the impact of agricultural input expenses, such as fertilizer, is greater now than ever before (Alexander *et al*., 2023). After the war, determining the link between international fertilizer prices and food commodity prices is very essential for food security and commodity market stability (Behnassi and Haiba, 2022). Many studies have been conducted on how the wars impact global food security and fertilizer directly or indirectly (Alexander *et al*., 2023; Ben Hassen and El Bilali, 2022; Bentley *et al*., 2022; Hatab, 2022). They studied the connection between the cost of food and fertilizer and these studies predicted that if fertilizer prices stay at their historically high levels, food prices will continue to rise. Global agricultural production has expanded dramatically, enabling the current population increase. The use of inorganic fertilizers to create and sustain high crop yields is a crucial part of agricultural output. However, given the effects of fertilizer runoff and the dependence of fertilizer production on limited non-renewable resources like mined phosphate- and potassium-bearing rocks, the long-term sustainability of these practices is uncertain. Undoubtedly, the recent fluctuations in the cost of food and agricultural commodities, particularly phosphate fertilizer, have sparked worries about new limitations on fertilizer production and how they may affect the affordability of fertilizer in developing countries. A new high price regime for necessary agricultural inputs has been indicated by the emergence of a scarcity price in the world's fertilizer markets, which will complicate ongoing efforts to ensure global food security (Elser *et al*., 2014; Patra, Mishra and Mithun, 2016).

Since global food prices doubled for the period between 2007 and 2008 and, currently, different scholars have investigated on the causes and consequences of food price in relation to global food security. Nevertheless, rather than fertilizer prices, the relationship between energy prices (crude oil, biofuel, and natural gas) and food prices has been the focus of several studies (Aleksandra and Joanna, 2020; Kirikkaleli and Darbaz, 2021; Nazlioglu, 2011; Zeneli, 2022). Even though the role of energy prices is large in determining food prices, the impact is not direct. However, the effect of fertilizers on crop yield that directly determine food price is unquestionable. Etienne (2016) examined the short- run and long-term price dynamics between, fertilizer, and maize markets using a vector error correction model. The findings showed a significant long-term price relationship between corn and fertilizer. Strubenhoff (2023) examined the potential effects of global energy and fertilizer markets on food security, taking into account possible outcomes from the conflict between Russia and Ukraine. They recommended that farmers reduce input levels they are unable to afford. The ratio of

fertilizer to food costs, as measured by the World Bank's fertilizer affordability index, is at all-time high.

The study conducted by Hinnerk and Śpiewanowski (2014) confirmed that high fertilizer prices directly indicate high food prices. According to the study, the link is crucial to understanding the recent food crisis during which prices rose by 40% on average. Furthermore, this study concluded that while many factors contribute to food crisis the role of fertilizers should be seriously taken in to account. Gnutzmann and Spiewanowski (2016) investigate the co-movement of fertilizer and food price indices monthly time series data ranged from 1960 to 2015 and the result of their study explained that a doubling in fertilizer prices leads to a long-run food price increase of 44%. The study conducted by Oluseyi, Feng and Patton (2021) on the dynamic causal relationship between phosphate rock, fertilizers and wheat prices suggest that there exist a long-run relationship between phosphate rock, fertilizers and wheat prices.

Despite fertilizer playing an essential role in agricultural production and food security, recent research on the linkage between food prices and fertilizer prices are relatively few, and there is no sufficient empirical evidence on the causal relationship between fertilizer price and food commodity price. Therefore, this study aims to analyze short run and long-run causal relationship between fertilizer price and food commodity price with special attention to Toda–Yamamoto time domain and frequency domain causality test.

## Materials and Methods

### *Sampling Scheme*

The purpose of this study is to examine the causal relationship between the price indices of food commodities and fertilizer. The World Bank provided monthly commodity price index data that covered the period from January 1980 to May 2023 with the base year of 2010, which was employed in this study. Both the food price index and the fertilizer price index were taken into account as factors. The components of the fertilizer price index used are nitrogenous, potassium, phosphate, and natural phosphate rock, with corresponding proportions of 16.9%, 21.7%, 20.1, and 41.3%. Grains, vegetable oil/meals, and other food make up 28.2%, 40.8%, and 31% of the food price index, respectively. The pricing index includes barley, wheat, maize, and rice as grains. Soybeans, soybean oil, soybean meal, palm oil, coconut oil, and groundnut oil are examples of vegetable oils and meals. Finally, the other food component consists of oranges, sugar, bananas, chicken, and meat.

### *Method of Analysis*

The Zivot–Andrews unit root test was used in this study to determine if the data was stationary since it permits testing of the unit root in situations where there is a single structural break in the time series (Zivot and Andrews, 2002). To investigate the causality between fertilizer and food commodity price, Toda–Yamamoto causality test was employed. This test is better than the traditional causality test because it removes issues with structural breaks and allows us to take any potential structural breaks into account.

The primary causality test in this study used a frequency domain test called the spectral BC causality test to determine the dynamic causality (short and long run co-movement) between the food price index and the fertilizer price index (Breitung and Candelon, 2006). Since the Granger causality test is primarily based on predictions for a single period ahead of time, it is typically inappropriate for distinguishing between long- and short-term effects. Put another way, there may be variations in the degree of causality across different frequency bands, which traditional causality tests are unable to detect (Gül and Özer, 2018; Ozer and Kamisli, 2016). For time domain causality and frequency domain causality, *'time'* refers as ability of indicating when a certain variation happens and '*frequency'* refers to a component which measures the degree of a certain variation (Tiwari, 2014). The frequency, ω, can be translated into a cycle or periodicity of T months by $T = 2\pi/\omega$, where T is the length of the period (in this study represents months). The higher the frequency, the lower the period.

Once all the data were downloaded, they were processed using statistical software such as STATA version.17, and E-views 9. Descriptive statistics and inferential statistics were applied. Descriptive analyses provided information on the variables mean, median, maximum and minimum values, standard deviation, skewness kurtosis, and jarque-bera probability. Inferential statistics analysis aimed to test the statistical causal relationships between the variables.

## Results and Discussion

Table 1 presents the Summary statistics of the variables under study. The minimum and maximum price for fertilizer were 25.09 and 293.72, respectively. For food commodity, 37.78 and 169.03, 35.06 and 172.75, 39.65 and 151.42 were the maximum and minimum price indices for grains, oils and other food, respectively. The average price for fertilizer was 68.71. The average price for grains, oils and other food were 78.15, 72.09 and 75.36, respectively. Since the p-value of Jarque-bera test result was less than the significance level the null hypothesis of normality was rejected.

Table 1: Descriptive statistics of variables under study

| *Parameter* | *Fertilizer* | *Grains* | *Oils* | *Other Food* |
|---|---|---|---|---|
| Mean | 68.71124 | 78.15176 | 72.09006 | 75.36184 |
| Median | 45.91089 | 66.59040 | 61.19569 | 65.08712 |
| Maximum | 293.7262 | 169.0373 | 172.7550 | 151.4229 |
| Minimum | 25.09070 | 37.78754 | 35.06014 | 39.65527 |
| Std. Dev. | 49.37553 | 29.59007 | 28.68571 | 24.23089 |
| Skewness | 1.887931 | 1.089471 | 0.991549 | 0.702848 |
| Kurtosis | 6.638550 | 3.300584 | 3.106688 | 2.622776 |
| Jarque-Bera | 596.8962 | 105.0280 | 85.61903 | 45.98427 |
| Probability | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

Table 2 presents the correlation of the variables under study. A strong positive correlation is observed between almost all variable under investigation, indicating the interaction between those variables in both short run and long run would be reasonable.

Table 2: Correlation between the variables

| *Commodity* | *Fertilizer* | *Grains* | *Oils* | *Other Food* |
|---|---|---|---|---|
| Fertilizer | 1 | 0.889019 | 0.880950 | 0.831273 |
| Grains | 0.889019 | 1 | 0.953625 | 0.858643 |
| Oils | 0.880950 | 0.953625 | 1 | 0.881827 |
| Other Food | 0.831273 | 0.858643 | 0.881827 | 1 |

Table 3 presents stationarity test of the data. The null hypothesis was that the variables have a unit root at their level. Based on the test results, even though the oils variable seems stationary at levels, the other variables under study were stationary at the first difference.

Table 3: Zivot–Andrews unit root test

| *Series in level* | | | | |
|---|---|---|---|---|
| | *Fertilizers* | *Grains* | *Oils* | *Other-food* |
| C | -4.235 | -3.836 | -4.772** | -3.128 |
| | [2006M11] | [2005M12] | [2006M10] | [1995M03] |
| C&T | -4.212 | -3.812 | -4.698 | -3.488 |
| | [2006M11] | [2005M12] | [2006M10] | [2004M01] |
| Series in first differences | | | | |
| C | -7.3333*** | -6.454*** | -7.283*** | -7.734*** |
| | [2008M09] | [2009M11] | [2003M10] | [2003M09] |
| C&T | -7.438*** | -7.288*** | -7.745*** | -7.794*** |
| | [2008M09] | [2005M09] | [2005M12] | [2003M09] |

Note: C and C&T denote constant and constant and trend in the ZA unit root test, respectively. ** and ***, respectively, for 5% and 1% significance. The numbers in bracket represent break points.

To determine the causal relationship between the fertilizer price index and food price indexes, the Toda–Yamamoto tests were employed within the time domain causality framework. The result of these tests are presented in table 4. According to the Toda–Yamamoto causality test results, fertilizers' price changes cause the oil and grains price changes at a 1% and 10% significant level, respectively. However, there is no causality from the fertilizers price index to the other food price index. The result of fertilizer price causality to oil and grain price is parallel with the study of (Alexander *et al*., 2023) that showed that increase in fertilizer price lead to higher food commodity price, which is in line with the study made by Gnutzmann and Spiewanowski (2016).

Causality was also found from the grains price index to fertilizer price index, oils price index to fertilizers price index, at 1% significance level. The result also reveals the causality of oils to grains and grains to oils at 1% and causality from oils to other food at 5% significance level.

In addition to the time domain causality tests, the Breitung–Candelon frequency domain spectral causality test is performed to explore the causal relationship between the fertilizers price index and food price indexes at different frequencies. The results of this test are illustrated in figures 1 to 6. Blue lines indicate test statistic; red lines indicate a

5% level of significance; and green lines indicate a 10% significance at different frequencies between the intervals (0, π). In figure 1, it is shown that at the 5% significance level, the null hypothesis that the fertilizer price index does not granger-cause the grains price index can be rejected for frequencies in the intervals of 1.08–1.64 and 2.71–3.14. Moreover, the results indicate that there is some causality of fertilizer price to grain price for frequencies out of 1.08-1.64 and 2.71-3.14.

Table 4: Toda-Yamamoto Causality test result

| *Set No.* | *Variables* | *Ho* | *Wald $X^2$ stat* | *P-value* |
|---|---|---|---|---|
| 1 | Fertilizer | Grains ≠> Fertilizer | 22.83512 | 0.0018*** |
| | Grains | Fertilizer ≠> Grains | 13.55940 | 0.0596* |
| 2 | Fertilizer | Oils ≠> Fertilizer | 30.54915 | 0.0001*** |
| | Oils | Fertilizer ≠> Oils | 19.37234 | 0.0071*** |
| 3 | Fertilizer | Other food ≠> Fertilizer | 9.155750 | 0.2417 |
| | Other Food | Fertilizer ≠> Other food | 3.413241 | 0.8443 |
| 4 | Grains | Oils ≠> Grains | 34.11304 | 0.0000*** |
| | Oils | Grains ≠> Oils | 18.75831 | 0.0090*** |
| 5 | Grains | Other food ≠> grains | 7.298938 | 0.3984 |
| | Other food | Grains ≠> Other food | 5.177511 | 0.6383 |
| 6 | Oils | Other food ≠> oils | 8.032395 | 0.3297 |
| | Other food | Oils ≠> other food | 14.37824 | 0.0448** |

Note: *, ** and ***, respectively, for 10%, 5% and 1% significance level

The null hypothesis that the fertilizer price index does not granger-cause the oils price index cannot be rejected for all frequencies in the intervals of 0-3.14, at 5% significance level (Figure 2). These results reveal that there is no short-run and long-run causal relationship between fertilizer price and oil price. The results depicted in figure 3 also suggest that there is no granger-causes from fertilizer price index to other food price index for all frequencies at both 5% and 10% significance level. The results indicate that there is no short-run and long-run causal relationship between fertilizer and other food items. This result is in contrast with Gnutzmann and Spiewanowski (2016) whose study indicated a long run relationship between fertilizer price indices and food commodity price indices.

In the reverse direction, the result in figure 4 shows that, at 5% significance level, the null hypothesis that the grains price index does not ganger-cause the fertilizer price index can be rejected for all frequencies in the intervals of 0 to 3.14. Thus, this result suggests that there is both a permanent (long-term) and temporary (short-term) causality from grains price index to fertilizer price index.

Frequencies in the intervals of 0–2.14 and 2.25-3.14 suggest that the oils price index granger-causes the fertilizer price index in the long term and short term at 5% significance level (Figure 5). The null hypothesis that the other food price index does not granger-cause the fertilizer price index can also be rejected for frequencies in the intervals of 0–1.57, which indicates a permanent long-term causality at 5% significance level (Figure 6).

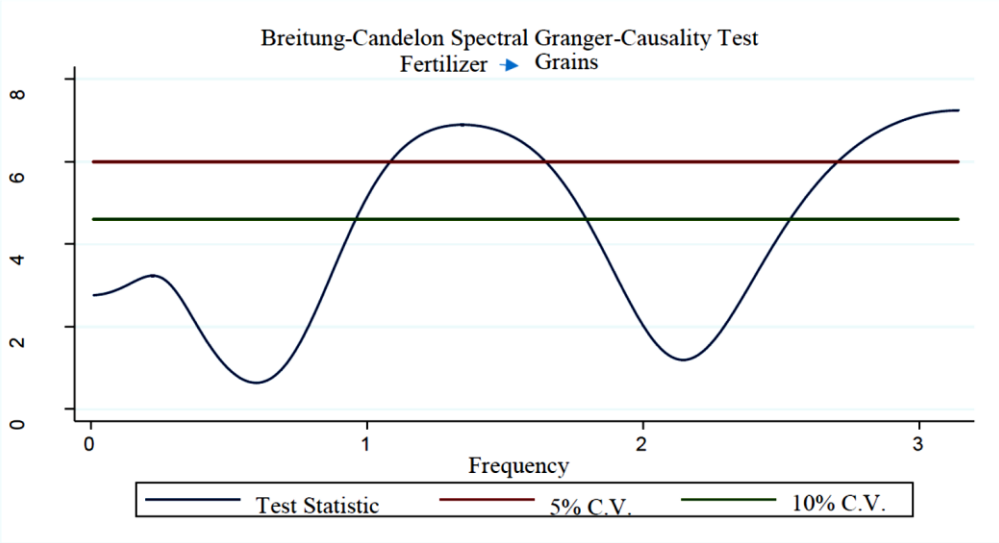


Figure 1: Spectral BC causality from fertilizer to grains

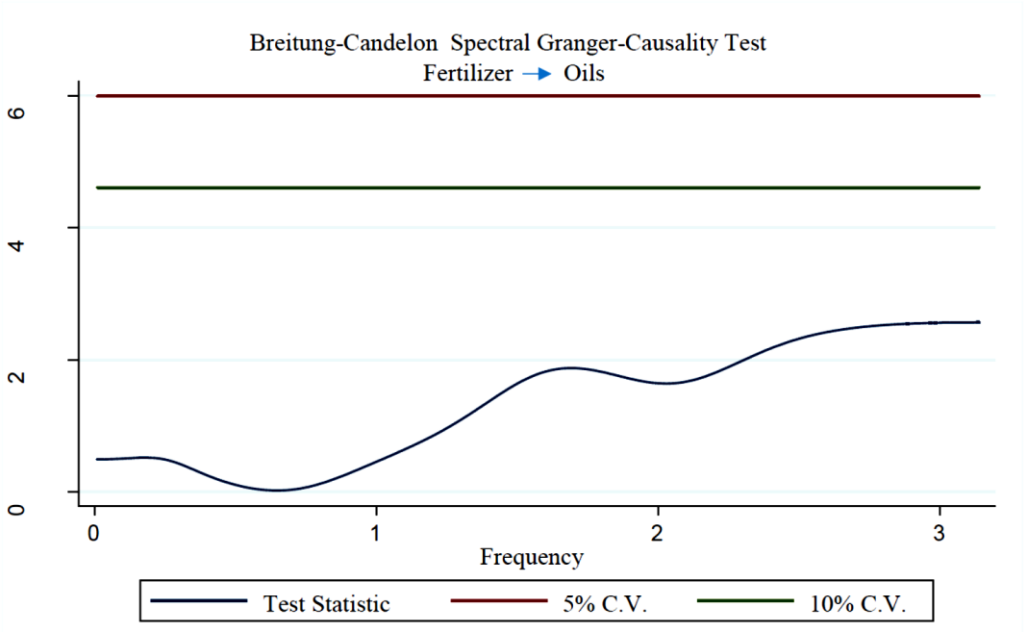


Figure 2: Spectral BC causality from fertilizer to oils

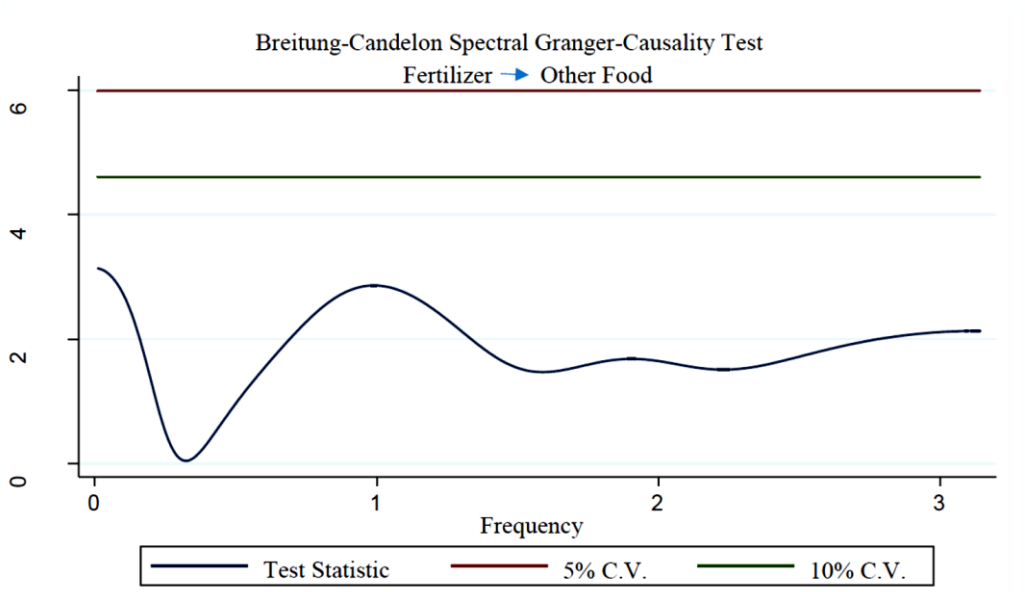


Figure 3: Spectral BC causality from fertilizer to other food

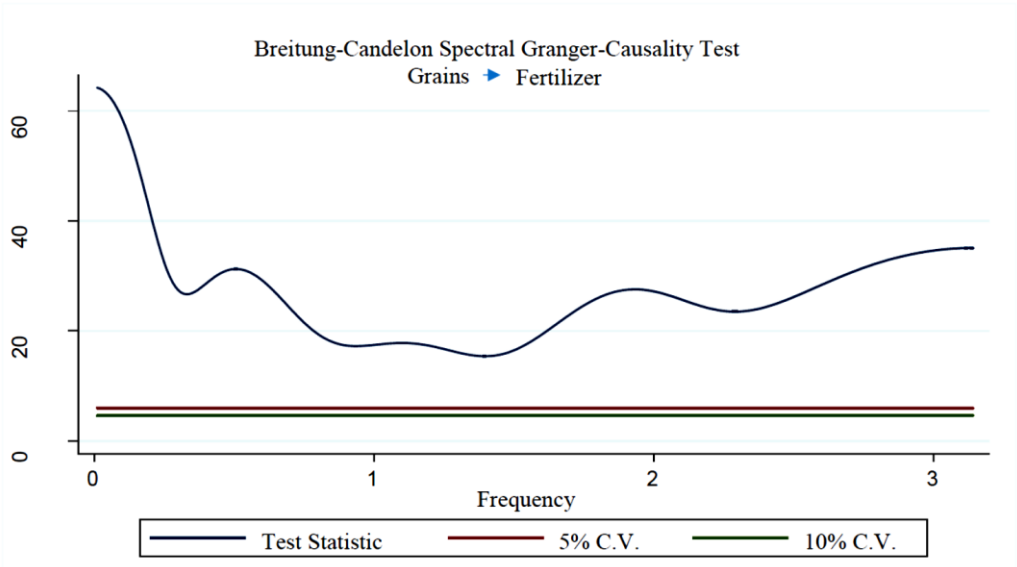


Figure 4: Spectral BC causality from grains to fertilizer

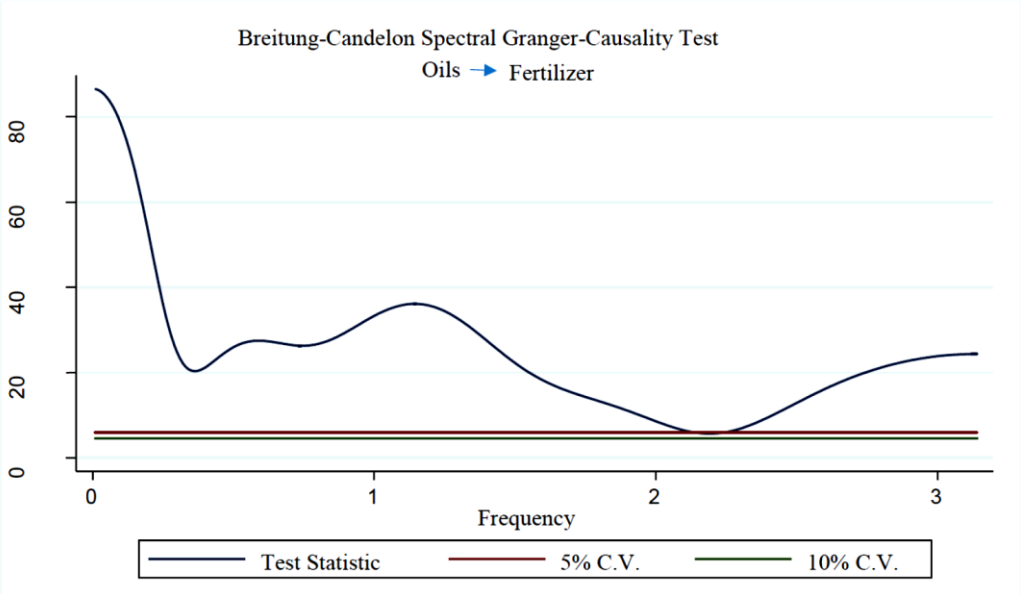


Figure 5: Spectral BC causality from oils to fertilizer

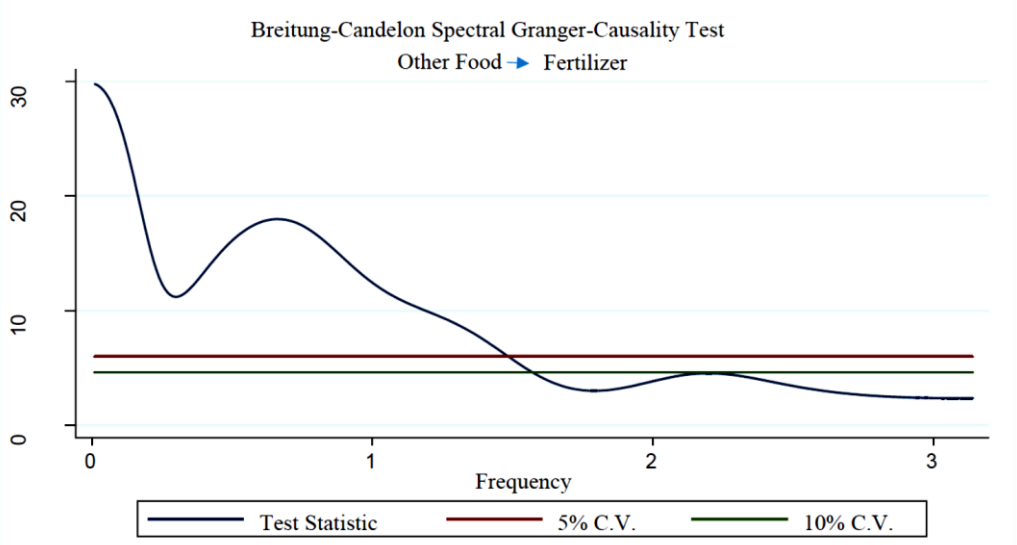


Figure 6: Spectral BC causality from other food to fertilizer

## Conclusion

This paper assesses a link between fertilizer price and food commodity prices (grains, oils and other food) by employing monthly data from 1980M1 to 2023M5 and attempts to provide new finding from the existing food price through using literature and relatively new methodology. The Toda–Yamamoto time domain causality tests revealed that fertilizers have a bidirectional causal relationship with both grains and oils.

Conversely, the test showed there is no interactions between fertilizer and other food that indicate fertilizer price and other food price do not cause each other. The spectral granger causality imply that there is a bidirectional long-term causality between fertilizer and grain price, which also supports the time domain causality result. The tests also showed the unidirectional causality of fertilizer with both oils and other food price. According to the frequency domain causality test results, the null hypothesis that suggests there is no causal relationship from fertilizer to oils and from fertilizer to other food price is accepted. On the other hand, the frequency domain causality test result showed that there is a long-term and permanent causality from food commodity price (grains, oils and other food) to fertilizer price at 5% significance level. Since world population is increasing and demand for food is also increasing, the findings can appeal to agrarian organizations and policymakers. The result is also significant for both national and international investors in this area.

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## Author's Declarations and Essential Ethical Compliances

*Author's Contributions (in accordance with ICMJE criteria for authorship)*
This article is 100% contributed by the sole author. He conceived and designed the research or analysis, collected the data, contributed to data analysis and interpretation, wrote the article, performed critical revision of the article, edited the article, and supervised and administered the field work.

*Funding*
No financial support was received for the research and writing of this article.

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The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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